# EXHIBIT V

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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Metallic access networks

# Very high speed digital subscriber line transceivers 2 (VDSL2)

Recommendation ITU-T G.993.2

International Telecommunication Union

ITU-T G-SERIES RECOMMENDATIONS

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# Recommendation ITU-T G.993.2

## Very high speed digital subscriber line transceivers 2 (VDSL2)

**Summary**

Recommendation ITU-T G.993.2 specifies an access technology that exploits the existing infrastructure of copper wires that were originally deployed for POTS services. It can be deployed from central offices, from fibre-fed cabinets located near customer premises, or within buildings. This Recommendation is an enhancement to ITU T G.993.1 that supports asymmetric and symmetric transmission at a bidirectional net data rate up to 200 Mbit/s on twisted pairs using a bandwidth up to 30 MHz.

This version of this Recommendation integrates all the previous amendments and corrigenda with the 2011 version of Recommendation ITU-T G.993.2.

This version of Recommendation ITU-T G.993.2 corrects or adds the following functionality:

– Method to address the misestimation of the SNR during MEDLEY (Amendment 2)
– Segmentation of SOC messages for profile 35b (Corrigendum 1)
– Annex D: Long reach VDSL2 (Amendment 3)
– Near-end anomalies for loss-of-power, host-reinit and spontaneous interruptions (Amendment 4)
– Addition of operation per the North American region for profile 35b (Annex Q) (Amendment 4)
– Addition of operation per the China region for profile 35b (Annex Q) (new)
– Addition of Successful SRA counter (new)
– Long reach VDSL2 corrigendum related to MAXNOMATP (new)
– Corrigendum to MAXMASK definition in Table 7-5 (new)
– Corrigendum to use of US0 with 35b profile for the North-America region (new).

**History**

| Edition | Recommendation | Approval | Study Group | Unique ID* |
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| 2.2 | ITU-T G.993.2 (2011) Cor. 1 | 2012-06-13 | 15 | 11.1002/1000/11642 |
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| 2.4 | ITU-T G.993.2 (2011) Amd. 3 | 2013-04-22 | 15 | 11.1002/1000/11888 |
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| 2.6 | ITU-T G.993.2 (2011) Amd. 5 | 2014-01-13 | 15 | 11.1002/1000/12096 |
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| 3.2 | ITU-T G.993.2 (2015) Amd. 2 | 2016-03-29 | 15 | 11.1002/1000/12796 |
| 3.3 | ITU-T G.993.2 (2015) Cor.1 | 2016-11-13 | 15 | 11.1002/1000/13120 |
| 3.4 | ITU-T G.993.2 (2015) Amd. 3 | 2018-02-09 | 15 | 11.1002/1000/13306 |
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Broadband access, copper pairs, DMT modulation, 100 Mbit/s.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

## FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

# Recommendation ITU-T G.993.2

## Very high speed digital subscriber line transceivers 2 (VDSL2)

### 1 Scope

This Recommendation is an enhancement to [ITU-T G.993.1] that supports transmission at a bidirectional net data rate (the sum of upstream and downstream rates) up to 200 Mbit/s on twisted pairs. This Recommendation is an access technology that exploits the existing infrastructure of copper wires that were originally deployed for plain old telephone service (POTS).

This Recommendation specifies only discrete multi-tone (DMT) modulation and incorporates components from [ITU-T G.993.1] (VDSL), [ITU-T G.992.3] (ADSL2), and [ITU-T G.992.5] (ADSL2 plus).

Whilst POTS uses approximately the lowest 4 kHz and asymmetric digital subscriber line (ADSL) uses approximately 2 MHz of the copper wire spectrum, this Recommendation is defined to allow the use of up to 30 MHz of the spectrum. This Recommendation can be deployed from central offices, from fibre-fed cabinets located near the customer premises, or within buildings.

The availability of bandwidth up to 30 MHz allows ITU-T G.993.2 transceivers to provide reliable high data rate operation on short loops. Without the use of the US0 band, this Recommendation should operate reliably over loop lengths that are similar to those of [ITU-T G.993.1], or slightly longer lengths due to the mandatory support of trellis coding. The addition of the US0 band and means to train echo cancellers and time-domain equalizers (TEQs) also allows this Recommendation to provide reliable operation on loops up to approximately 2 500 metres of 26 American wire gauge (AWG) (0.4 mm).

This Recommendation defines a wide range of settings for various parameters (such as bandwidth and transmitter power) that could potentially be supported by a transceiver. Therefore, this Recommendation specifies profiles to allow transceivers to support a subset of the allowed settings and still be compliant with the Recommendation. The specification of multiple profiles allows vendors to limit implementation complexity and develop implementations that target specific service requirements. Some profiles are better suited for asymmetric data rate services, whereas other profiles are better for symmetric data rate services.

The annexes of this Recommendation include band plans and power spectral density (PSD) masks that address region-specific requirements.

Like [ITU-T G.993.1], this Recommendation defines upstream power back-off (UPBO) to mitigate far-end crosstalk (FEXT) caused by upstream transmissions on shorter loops to longer loops. The mechanism is the same as in [ITU-T G.993.1].

As with other ITU-T Recommendations in the ITU-T G.99x series, this Recommendation uses [ITU-T G.994.1] to initiate the transceiver training sequence.

Changes in this Recommendation relative to [ITU-T G.993.1] include:

- The definition of profiles to support a wide range of deployment scenarios (e.g., central offices, fibre-fed cabinets located near the customer premises, and within buildings).

For TPS-TC sublayer specifically, changes in this Recommendation relative to [ITU-T G.993.1] include:

- Support for STM interfaces;
- Support for PTM interfaces based on IEEE 802.3 64/65 octet encapsulation;
- Support for ToD-TC functionality for transport of time-of-day over VDSL2 links.

For PMS-TC sublayer specifically, changes in this Recommendation relative to [ITU-T G.993.1] include:

- Improved framing (based on [ITU-T G.992.3]);
- The definition of two latency paths and two bearer channels;
- Improved on-line reconfiguration (OLR) mechanisms (based on [ITU-T G.992.3]), including optional SRA, special operations channel (SOS), and dynamic interleaver change;
- Control of delay variation;
- Improved overhead channel;
- Improved forward error correction (FEC) capabilities, including a wider range of settings for the Reed-Solomon (RS) encoder and the interleaver;
- Improved interleaving with controlled memory-split between downstream and upstream;
- Support of all integer values of impulse noise protection (INP) up to 16 symbols;
- Optional impulse noise monitor (INM) function.

For PMD sublayer specifically, changes in this Recommendation relative to [ITU-T G.993.1] include:

- The definition, in annexes, of band plans up to 30 MHz to support a bidirectional net data rate up to 200 Mbit/s;
- Support for extension of the upper band edge of the US0 band to as high as 276 kHz (based on Annex M of [ITU-T G.992.3]);
- The definition of means to improve the performance of US0 (specifically, support in initialization for training of time domain equalizers and echo cancellers);
- A requirement to support the US0 band in the upstream direction for some profiles;
- Support for spectrum shaping of the US0 band in the upstream direction;
- Support for a management information base (MIB)-controlled PSD mask mechanism to enable in-band spectrum shaping (based on [ITU-T G.992.5]);
- Alternative electrical length estimation method (AELE-M1);
- Optional equalized FEXT UPBO method;
- A requirement for downstream and upstream transmitters to notch, simultaneously, 16 arbitrary operator-defined radio frequency interference (RFI) bands;
- Support for downstream maximum transmit power (profile dependent) of up to 20.5 dBm;
- Mandatory support of trellis coding (based on [ITU-T G.992.3]);
- The definition of receiver-determined tone ordering (based on [ITU-T G.992.3]);
- Mandatory support of all integer-bit constellations from 1 bit to 15 bits;
- Support for optional cyclic extension (CE) lengths as large as ¼ of a symbol period;
- Optional virtual noise (VN) mechanism;
- The definition of VTU-R receiver-selected pilot tone(s), including the option not to select a pilot tone;
- Insertion of a sync symbol after every 256 data symbols to signal OLR transitions;
- Improvements to initialization, including the definition of a channel discovery phase, a training phase, and a channel analysis and exchange phase;
- Definition of re-initialization policy parameters;
- Definition of link activation methods and procedures;
- Support for a VTU-R lineprobe stage during initialization;

- Support for a wide range of test parameters and accuracy requirements (based on [ITU-T G.992.3]);
- The definition of a loop diagnostic mode;
- Support for an optional all-digital mode;
- Definition of downstream and full vectoring-friendly operating modes.

## 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.117] Recommendation ITU-T G.117 (1996), *Transmission aspects of unbalance about earth*.

[ITU-T G.992.1] Recommendation ITU-T G.992.1 (1999), *Asymmetric digital subscriber line (ADSL) transceivers*.

[ITU-T G.992.3] Recommendation ITU-T G.992.3 (2009), *Asymmetric digital subscriber line transceivers 2 (ADSL2)*.

[ITU-T G.992.5] Recommendation ITU-T G.992.5 (2009), *Asymmetric digital subscriber line 2 (ADSL2) transceivers – Extended bandwidth ADSL2 (ADSL2 plus)*.

[ITU-T G.993.1] Recommendation ITU-T G.993.1 (2004), *Very high speed digital subscriber line transceivers (VDSL)*.

[ITU-T G.993.5] Recommendation ITU-T G.993.5 (2019), *Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers*.

[ITU-T G.994.1] Recommendation ITU-T G.994.1 (2018), *Handshake procedures for digital subscriber line transceivers*.

[ITU-T G.995.1] Recommendation ITU-T G.995.1 (2001), *Overview of digital subscriber line (DSL) Recommendations*.

[ITU-T G.997.1] Recommendation ITU-T G.997.1 (2019), *Physical layer management for digital subscriber line transceivers*.

[ITU-T G.998.4] Recommendation ITU-T G.998.4 (2018), *Improved impulse noise protection for digital subscriber line (DSL) transceivers*.

[ITU-T G.9954] Recommendation ITU-T G.9954 (2007), *Home networking transceivers – Enhanced physical, media access, and link layer specifications*.

[ITU-T I.361] Recommendation ITU-T I.361 (1999), *B-ISDN ATM layer specification*.

[ITU-T I.432.1] Recommendation ITU-T I.432.1 (1999), *B-ISDN user-network interface – Physical layer specification: General characteristics*.

[ITU-T O.9] Recommendation ITU-T O.9 (1999), *Measuring arrangements to assess the degree of unbalance about earth*.

[ITU-T O.41] Recommendation ITU-T O.41 (1994), *Psophometer for use on telephone-type circuits*.

In case the parameter value as defined in clause 11.4.1 is represented by a number of bits that is not an integer number of octets, the parameter value shall be mapped to the LSBs of the message octets. Unused more significant bits shall be set to ZERO for unsigned parameter values and shall be set to the sign bit for signed parameter values.

#### 12.4.1.1 SOC message mapping during loop diagnostic mode

In order to increase the robustness of the messages exchanged during the channel discovery and training phases of the loop diagnostic mode, all SOC messages shall be sent using 1 information bit per DMT symbol, where each bit is sent 5 times in 5 consecutive DMT symbols. The mapping of the SOC bits to subcarriers during loop diagnostic mode shall be as summarized in Table 12-72.

**Table 12-72 – Bit mapping during loop diagnostic mode**

| Subcarrier index | Constellation bits for SOC bit = 0 | Constellation bits for SOC bit = 1 |
|---|---|---|
| Even | 00 | 00 |
| 1, 11, 21, …,10*n*+1,... | 00 | 11 |
| 3, 13, 23, …,10*n*+3,... | 00 | 11 |
| 5, 15, 25, ... ,10*n*+5,... | 00 | 11 |
| 7, 17, 27, …,10*n*+7,... | 00 | 11 |
| 9, 19, 29, …,10*n*+9,... | 00 | 00 |

When the SOC is inactive, the symbols shall be transmitted as described in clause 12.3.3 without modification.

### 12.4.2 Channel discovery and training phases of loop diagnostic mode

#### 12.4.2.1 SOC messages exchanged during the channel discovery and training phases of loop diagnostic mode

Other than O-PRM and R-PRM, the SOC messages for the channel discovery phase and the training phase of the loop diagnostic mode shall be the same as for the initialization procedure described in clauses 12.3.3 and 12.3.4, respectively. The test parameters for the quiet line noise (QLN) and the channel characteristics function (Hlog) shall be measured and exchanged during the channel discovery phase in the O-PRM-LD and R-PRM-LD messages, which replace O-PRM and R-PRM. The test parameters are listed in Table 12-73 and defined in clause 11.4.1.

**Table 12-73 – Test parameters exchanged during the channel discovery phase in loop diagnostic mode**

| Abbreviation | Name |
|---|---|
| Hlog($k \times G \times \Delta f$) | Channel characteristics per subcarrier group, dB |
| QLN($k \times G \times \Delta f$) | Quiet line noise per subcarrier group, dBm/Hz |

##### 12.4.2.1.1 VTU-O message O-PRM-LD

**Table 12-74 – Description of message O-PRM-LD**

| | Field name | Format |
|---|---|---|
| 1 | Message descriptor | Message code |
| 2 | Downstream MEDLEY reference PSD (MREFPSDds) | PSD descriptor |